

REMARKS

Claims 1-8 were pending. Claims 1-5 have been amended and claims 6-8 have been canceled. New claims 9-15 have been added. Reconsideration of the present application is respectfully requested.

At the outset, the Examiner is thanked for the thorough review and consideration of the present application. The Examiner's Office Action dated November 4, 2003 has been received and the contents carefully noted.

In the Office Action, the Examiner objected to Figures 10 and 11 because they are not designated by a legend such as --Prior Art--. The Examiner objected to Figures 5, 6, and 11 because the word "hole" should be replaced with --Hall--. In response, Applicants have submitted replacement drawing sheets including amended FIGs. 5, 6, 10 and 11. Specifically, Figures 10 and 11 have been labeled "Prior Art" and the word "hole" has been replaced with the word --Hall-- in Figures 5, 6, and 11. Applicants respectfully request the objection to the drawings be withdrawn.

The Examiner objected to the specification and the claims because the word "hole" appearing throughout should be --Hall--. Regarding this objection, Applicants submit a clean and marked-up copies of a substitute specification herewith and amendments to the claims to correct all of the occurrences of the misspelling of the word --Hall--. As indicated in the attached Statement Under 37 C.F.R. 1.125(b), no new matter has been added. Applicants respectfully request that the objection to the drawings be withdrawn.

The Examiner rejected claims 1 and 8 under 35 USC 102(b) as being anticipated by Shinohara et al. (US Pub. No. 2001/0013731). This rejection is respectfully traversed.

Claim 1 has been amended to recite, *inter alia*, first, second, and third Hall elements, and to include the features of canceled claims 6-8. These features are disclosed in the specification

for example on page 8, paragraph beginning on line 25 to page 9, line 25, page 12, paragraph beginning on line 9, page 17, paragraph beginning on line 12, and page 18, paragraph beginning on line 25. In the present invention, a brushless motor includes first, second, and third Hall elements spaced by a predetermined angular distance so that they detect a magnetic field of the sensor magnet. The sensor magnet rotates integrally with the rotor in a constant angular relationship with the rotor. The output signals from these Hall elements enable detection of the rotary position of the rotor so that the brushless motor is driven based on the detected positions. Thus, the brushless motor suppresses noise and vibration resulting from relative positional displacement between the sensor magnet and Hall elements caused by assembling errors and the like.

Shinohara et al. discloses a motor 12 including a detection plate 17 formed from a magnetic material, sensor portions 23a-23c disposed at substantially equal distances from one another and at a 10° angle with respect to a rotation center of the detection plate 17. (See Figure 3 and Paragraph [0039]).

However, Shinohara et al. fails to disclose the features recited in claims 1, namely, a substrate including first, second, and third Hall elements, power supply terminals, and a power supply control circuit to achieve the novel and nonobvious advantages of the present invention.

Rather, Shinohara et al. merely discloses a position sensor 23 including sensor portions 23a-23c which detect a rotational position of the rotor. The position sensor 23 is disposed at a position where the detection plate 17 and the stator windings 19b of the motor 12 are superimposed in the radial direction. The position sensor 23 is fixed to the motor housing 11 by means of two bolts 28. (See Paragraphs [0046] and [0044]). There is no discussion of substrate, Hall elements, power supply terminals, and power supply control circuit. The reference is silent with regard to using and locating Hall elements in the manner recited in claim 1. Further, there is

no discussion that the brushless motor is used as a blower motor of a vehicle air-conditioning system.

In the present invention, as a result of the positioning of the Hall elements, discrepancies in phase difference between the position signals are lessened, whereby the varying component superimposed in the phase currents is reduced. Thus, noise is decreased and the comfort level of the vehicle occupants is improved.

Therefore, as the Shinohara et al. reference fails to anticipate the invention as recited in claim 1, Applicants respectfully request that the rejection under 35 USC 102(b) be withdrawn.

The rejection of claim 8 is now moot in view of the cancellation of this claim. However, the features of claim 8 have been incorporated into claim 1 and are allowable as discussed above.

The Examiner rejected claims 2-5 under 35 USC 103(a) as being unpatentable over Shinohara et al. in view of Kyodo (US Patent No. 5,796,231). This rejection is respectfully traversed.

The Examiner admits that Shinohara et al. does not teach the features recited in claims 2-5. The Examiner cites Kyodo in an attempt to cure the deficiencies of Shinohara et al.

Kyodo teaches a rotation position detecting device for a sensor-less [emphasis added] motor and motor device. The detecting device includes a sensor signal generating circuit 3. (See Column 4, Lines 6-18). The detection device can detect the rotation position of a rotor magnet by detecting the change of the current value. (See Abstract). A phase relation between the sensor signals for the first phase and for the second phase which are outputted from the rotation position detecting device is the same as the phase relation between the amplitude output of the induction voltage obtained from the stator coil corresponding to the angle displacement of the rotator. (See Column 12, Lines 25-38).

However, Kyodo fails to cure the deficiencies of Shinohara et al. because Kyodo fails to disclose the features recited in claim 1, namely, a substrate including first, second, and third Hall elements, power supply terminals, and a power supply control circuit to achieve the novel and nonobvious advantages of the present invention.

Rather, Kyodo merely teaches controlling the phase of the motor based on a rotation position detection signal (response signal) when a sensor signal is input. (See Column 22, Lines 6-52). There is no discussion of magnetic sensors, specifically Hall elements, and locating the Hall elements in the manner recited in claim 1. Further, the sensor-less motor of Kyodo teaches away from the brushless motor of the present invention which includes Hall elements. A modification of the motor in Shinohara et al. that includes magnetic sensors with the sensor-less motor in Kyodo would render it unsatisfactory for its intended purpose. (See MPEP 2144.05). Thus, the phase in Kyodo is not adjusted by adjusting the phases of output signals from any Hall elements as recited in claim 2, and by inversion as recited in claims 3-5.

In the present invention, as a result of the positioning of the Hall elements, discrepancies in phase difference between the position signals are lessened, whereby the varying component superimposed in the phase currents is reduced.

Therefore, as the combination of references fails to make obvious the invention as recited in claim 1, Applicants respectfully request that the rejection under 35 USC 103 (a) be withdrawn.

Moreover, as claims 2-5 depend from independent claim 1, these claims are also allowable for the same reasons as their respective base claim.

The Examiner rejected claims 6 and 7 under 35 USC 103(a) as being unpatentable over Shinohara et al. in view of Kurita (US Patent No. 5,610,457). This rejection is respectfully traversed.

The Examiner admits that Shinohara et al. does not teach the features recited in claims 6 and 7. The Examiner cites Kurita in an attempt to cure the deficiencies of Shinohara et al.

Kurita teaches a brushless motor with Hall elements for controlling the drive circuit and for detecting the position of the rotor by use of magnetic flux varying means. Three Hall elements 18U, 18V, and 18W are arranged on a printed circuit board 2 in such a manner that they are located outside a magnet 6. (See Column 3, Lines 28-36). An IC 38 is mounted on the printed circuit board 2 and connected to the output terminals of the Hall elements, 18U, 18V, and 18W, and includes a drive circuit 38a. (*Id.* at Lines 37-47). A cut out portion 35a is formed in the rotor casing 35 for varying the magnetic flux. (*Id.* at Lines 14-27).

However, Kurita fails to cure the deficiencies of Shinohara et al. because Kurita fails to teach that the angular distance between two of the Hall elements is set to be less than 180° as recited in claim 1 to achieve the novel and nonobvious advantages of the present invention.

Rather, Kurita merely discloses Hall elements and a magnetic flux varying means for obtaining an index signal, but is silent as to the disposition of the Hall elements.

In contrast, in the present invention, as a result of the positioning of the Hall elements, discrepancies in phase difference between the position signals are lessened, whereby the varying component superimposed in the phase currents is reduced.

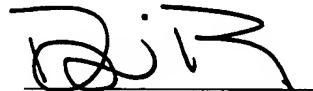
Therefore, as the combination of references fails to make obvious the invention as recited in claim 1, Applicants respectfully request that the rejection under 35 USC 103 (a) be withdrawn.

The rejection of claims 6 and 7 is deemed moot in view of the cancellation of these claims. However, the features of claims 6 and 7 have been incorporated into claim 1 and are allowable as discussed above.

Newly added independent claim 9 recites features similar to claim 1, including a mechanical angle between Hall elements of less than 180°. Therefore, Applicants submit that independent claim 9, dependent claim 10 (support can be found on page 10 of the specification), dependent claim 11 (features from claim 1), and dependent claims 12-15, which correspond to claims 2-5, should be allowable at least for the same reasons with respect to claims 1-5.

In view of the above remarks and amendments, the present application is now in condition for allowance. Applicants therefore respectfully request a prompt Notice to that effect. Please charge any fees that may be due, or credit any refunds, to Deposit Account No. 50-1147.

Respectfully submitted,



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BRUSHLESS MOTOR

CROSS REFERENCE TO RELATED APPLICATION

5 This application is based upon, claims the benefit of priority of, and incorporates by reference, the contents of Japanese Patent Application No. 2002-217835 filed July 26, 2002.

BACKGROUND OF THE INVENTION

1. Field of the Invention

10 The present invention relates to a brushless motor having a sensor magnet and magnetic sensors for detecting the rotary position of the motor rotor.

2. Description of the Related Art

15 Japanese Patent Laid-Open Publication No. Hei 11-356024 shows a brushless motor used as a blower motor for a vehicle air-conditioning system. It has a 6-pole rotor magnet fixed to a yolk and a disk-like 6-pole sensor magnet attached to a lower end of the output shaft. A circuit board is attached in close proximity and is parallel to the bottom face of the sensor magnet. On the circuit board are mounted an excitation circuit 20 for excitation coils, connection terminals corresponding to power supply terminals of the excitation coils, and three hole Hall elements arranged opposite the circumference of the sensor magnet.

25 Fig. 9 illustrates a prior art construction of the layout of the hole Hall elements. The 6-pole sensor magnet 2 is coupled on the rotary shaft 1, and the hole Hall elements 3w,

3u, and 3v are spaced from each other at an angle of either 40° or 80° around this rotary shaft 1. Fig. 9 shows the latter case. The excitation circuit 4 includes a 3-phase bridge inverter circuit and controls power supply to the excitation coils 5u, 5v, and 5w in accordance with output signals from the hole Hall elements 3u, 3v, and 3w for rotating the rotor.

Because the sensor magnet 2 is attached to the rotary shaft 1 while the hole Hall elements 3u, 3v, and 3w are mounted on the circuit board, which is then attached to a motor holder, 10 there are cases where accumulated assembling errors have some bearing on the positional relationship between the sensor magnet 2 and hole Hall elements 3u, 3v, and 3w.

Fig. 10 shows a state in which there has been a change in relative positions of the sensor magnet 2 and hole Hall 15 elements 3u, 3v, and 3w because of assembling errors. The broken lines indicate the position where the sensor magnet 2 should ideally be located. As can be seen, because of the displacement of the sensor magnet 2 in the X-axis direction on the X-Y coordinate basis in the drawing, the angular distance 20 θ_1 between the hole Hall elements 3w and 3u is smaller than 80°, while the angular distance θ_2 between the hole Hall elements 3u and 3v is larger than 80°.

Fig. 11 shows the detected magnetic fields of the hole Hall elements 3u, 3v, and 3w in this state and position signals 25 Du, Dv, and Dw together with output states of the inverter circuit included in the excitation circuit 4 and input current in the inverter circuit (combined waveform of three phase

currents). As can be seen, the phase difference between the position signals Du, Dv, and Dw, based on which the power supply switching control is performed, is largely shifted from the electrical angle of 120°. Because of this the current in the excitation coils includes a superimposed component having a large phase shift cycle of 180° (electrical angle). This unbalanced phase current causes torque variations, which increase operation noise in a particular frequency band, for example, in a resonance frequency band of 200Hz to 300Hz, of the casing in which the motor is assembled, causing an unpleasant feeling to the vehicle occupant.

SUMMARY OF THE INVENTION

The present invention has been devised in light of the circumstances described above. A first object is to provide a brushless motor capable of suppressing noise and vibration resulting from relative positional displacement between the sensor magnet and magnetic sensors caused by assembling errors and the like.

According to a first aspect of the present invention, the first and third magnetic sensors are arranged with a predetermined angular distance so that they detect a magnetic field of the sensor magnet, which rotates integrally with the rotor in a constant angular relationship with the rotor. The output signals from these magnetic sensors enable detection of the rotary position of the rotor so that the brushless motor is driven based on the detected positions.

Assembling errors or the like during the manufacturing process can cause relative positional displacement between the sensor magnet and magnetic sensors. An analysis has shown that an error $\Delta\theta_1$ of the angular distance θ_1 between the first and 5 second magnetic sensors and an error $\Delta\theta_2$ of the angular distance θ_2 between the second and third magnetic sensors can be made smaller if the angular distances θ_1 and θ_2 are small. Meanwhile, to perform power supply switching control, position signals with a 120° phase offset (electrical angle) are 10 necessary.

Accordingly, the angular distances θ_1 and θ_2 are set to be the smallest possible angles of the angles less than 180° that are θ_a , $2\times\theta_a$, $4\times\theta_a$, $5\times\theta_a$, $7\times\theta_a$, $8\times\theta_a$, $10\times\theta_a$, $11\times\theta_a$, ..., where θ_a is a basic minimum angle and obtained by $360^\circ/(n\cdot3)$ (n 15 ≥ 2) (mechanical angle). If it is impossible to arrange the magnetic sensors with the minimum angle because of size limitations of the sensor magnet, then the next smallest angle should be selected.

With this arrangement, the output signals of the magnetic 20 sensors are less affected even if there is a change in relative positions of the sensor magnet and magnetic sensors, whereby variations in the phase currents are reduced, and operation noise and vibration are suppressed. Because there will be less discrepancy in alternating timing, efficiency deterioration can 25 be suppressed. Furthermore, because this arrangement can be achieved by altering the layout of the magnetic sensors, the cost increase is minimal.

According to a second aspect of the invention, phase adjusting means included in the brushless motor generates position signals having a mutual phase difference of 120° (electrical angle), whereby alternating current control is 5 performed using these position signals.

According to a third aspect of the invention, if the angular distance θ_1 or θ_2 (mechanical angle) is one of θ_a , $5 \times \theta_a$, $7 \times \theta_a$, $11 \times \theta_a$, and so on, i.e., if it is $(6m + 3 +/ - 2) \times \theta_a$ (as a mechanical angle), the position signals are obtained by 10 inverting phases of the output signals of the first and third magnetic sensors while the output signal of the second magnetic sensor is used as it is as a position signal. Thereby, position signals with a 120° phase difference (electrical angle) can be obtained. The effects of a fourth aspect of the 15 invention are the same.

According to a fifth aspect of the invention, the phase adjusting means is constructed so that it inverts the phases by reversing the polarity of the signal output terminals of the magnetic sensors, which are hole Hall elements. Therefore, no 20 circuit is necessary for phase adjustment.

According to a sixth aspect of the invention, with the substrate assembled in the system, power is supplied to the excitation coils via the power supply terminals on the substrate, and magnetic sensors on the substrate positioned in 25 close proximity to the sensor magnet detect the magnetic field thereof. Because the magnetic sensors are arranged on the substrate, assembly and component replacement are readily

carried out, and adverse effects of assembling errors, which may cause a change in relative positions of the sensor magnet and magnetic sensors, can be suppressed to a minimum.

According to a seventh aspect of the invention, because the control circuit for controlling power to the excitation coils is arranged on the substrate, rotation of the brushless motor can be initiated by merely supplying power thereto.

According to an eighth aspect of the invention, operation noise of the motor inside the vehicle is suppressed, thereby reducing unpleasant feelings for the vehicle occupants.

Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

Fig. 1 is a schematic representation of the electrical structure of a brushless motor according to a first embodiment of the present invention;

Fig. 2 is an exploded perspective view of the brushless motor;

Fig. 3 is a diagram illustrating relative positions of a sensor magnet and Hole Hall elements;

Fig. 4 is a diagram illustrating the relationship between ideal layout angles θ_0 and differentiation factors;

5 Fig. 5 is a waveform chart of a state in which there is no positional displacement between the Hole Hall elements and the sensor magnet;

10 Fig. 6 is a waveform chart of a state in which the sensor magnet has displaced in an X-axis direction relative to the Hole Hall elements;

Fig. 7 is a schematic representation of the electrical structure of a brushless motor according to a second embodiment of the present invention, shown in a manner similar to Fig. 1;

15 Fig. 8 is a schematic representation of the electrical structure of a brushless motor according to a third embodiment of the present invention, shown in a manner similar to Fig. 1;

Fig. 9 is a schematic representation of the electrical structure of a prior art brushless motor;

20 Fig. 10 is a diagram illustrating relative positions of a sensor magnet and Hole Hall elements displaced from each other; and

Fig. 11 is a waveform chart of a state in which the sensor magnet has displaced in the X-axis direction relative to the Hole Hall elements, shown in a manner similar to Fig. 6.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description of the preferred embodiments is

merely exemplary in nature and is in no way intended to limit the invention, its application, or uses.

(First Embodiment)

A first embodiment of the present invention will be 5 hereinafter described with reference to Fig. 1 to Fig. 6.

Fig. 2 is an exploded perspective view of a 3-phase brushless motor used as a blower motor of a vehicle air-conditioning system. Fig. 1 provides a schematic representation of the electrical structure of the brushless 10 motor. As shown in Fig. 2, the stator 12 is fixed in a resin motor holder 11, and the rotor 13 is supported by a bearing (not shown) such as to be rotatable relative to the stator 12. Excitation coils 14u, 14v, and 14w (see Fig. 1) of U-phase, V-phase, and W-phase are coiled around the stator core, and 15 respective power supply terminals 15u, 15v, and 15w, connected to each of the excitation coils, are extended downwards.

A 6-pole rotor magnet (not shown) is fixedly attached to an inner face of a rotor yolk 16. A fan 18 is fixed to the top end of an output shaft 17, and a sensor magnet 19 is attached 20 to the bottom end with a clasp 20 for stopping the magnet from coming off the output shaft 17. The sensor magnet 19 has six poles as shown in Fig. 1 as with the rotor magnet, i.e., N and S poles alternate every 60°. The rotor magnet and sensor magnet 19 are assembled so that a constant positional 25 relationship is maintained between their magnetic poles.

Beneath the motor holder 11 is attached a circuit board 21 with screws 22, on which is mounted a power supply control

circuit 23 (see Fig. 1) for supplying power to the excitation coils 14u, 14v, and 14w. The circuit board 21 is formed with through holes 21a, 21b, and insertion holes 21c. The power supply terminals 15u, 15v, and 15w pass through the fan-shaped hole 21a, and the output shaft 17 passes through the hole 21b. 5 Base ends of U-shaped connection terminals 24u, 24v, and 24w are fitted in the three insertion holes 21c and act as power supply terminals.

The base ends of the connection terminals 24u, 24v, and 10 24w are inserted in the insertion holes 21c and soldered so that they are electrically connected to output terminals of each phase in the power supply control circuit 23. To the distal ends of the connection terminals 24u, 24v, and 24w are coupled the distal ends of the power supply terminals 15u, 15v, 15 and 15w, respectively, whereby electrical connection is established between each of the power supply terminals 15u, 15v, and 15w and the circuit board 21.

The power supply control circuit 23 includes a 3-phase bridge inverter circuit 25 that is controlled by a control IC 20 23a, and the circuit board 21 includes a heat sink 26 for cooling switching elements (not shown) in this inverter circuit 25. The motor holder 11 is formed with an aperture 11a conforming to the shape of the heat sink 26, so that the upper face of the heat sink 26 will fit into the aperture 11a when 25 the circuit board 21 is attached to the motor holder 11 for effective heat dissipation.

The upper face of the circuit board 21 has three hole

Hall elements 27v, 27u, and 27w attached in this order in the forward direction of the rotor 13 so that they will be positioned opposite the circumference of the lower face of the sensor magnet 19. The ~~hole~~ Hall elements 27w, 27u, and 27v are 5 termed as "first, second, and third magnetic sensors" in the claims. These ~~hole~~ Hall elements 27v, 27u, and 27w are arranged on an opposite side of the through hole 21b as the through hole 21a and at a mechanical angular spacing of 20° around the output shaft 17 as shown in Fig. 1. Two output 10 terminals of the ~~hole~~ Hall elements 27v and 27w are reversely connected so as to invert the phases of their output signals. A phase adjusting means 28 is thus constructed.

A connector 29 is attached to the circuit board 21 for supplying a battery voltage VB of, for example, 14V, to the 15 power supply control circuit 23 and for applying rpm command signals Sr. The circuit board 21 is covered by a lower case 30 attached to the motor holder 11 by screws 31. The connector 29 is connected to an external harness (not shown) through a hole 30a formed in a side face of the lower case 30.

20 How the brushless motor operates is described below with reference to Fig. 3 to Fig. 6. In order for the power supply control circuit 23 to perform power supply switching control, position signals Du, Dv, and Dw must have a phase difference of 120 electrical degrees, which are obtained based on the output 25 signals from the ~~hole~~ Hall elements 27u, 27v, and 27w. To generate the position signals Du, Dv, and Dw using the phase adjusting means 28, the angles included between the ~~hole~~

Hall elements 27w and 27u and between the hole Hall elements 27u and 27v (hereinafter referred to as "layout angle θ ") around the output shaft 17 need to be one of the following mechanical angles: 20° , 40° , 80° , 100° , 140° , and 160° .

5 Applying this to a more general case, if the sensor magnet 19 and rotor magnet each have n poles, where $n \geq 2$, the layout angle θ can be expressed as the following equation (2), using a basic minimum angle θ_a obtained from the following equation (1). Since the hole Hall elements 27u, 27v, and 27w are arranged in the range of 360° , it follows that the layout angle θ is less than 180° .

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$$\theta_a = 360^\circ / (n \cdot 3) \quad \dots (1)$$
$$\theta = (3m + 1) \cdot \theta_a \text{ and } (3m + 2) \cdot \theta_a \quad (m \text{ is } 0, 1, 2, 3, \dots)$$

(2)

15 The power supply control circuit 23 switches the power supply on and off to the switching elements of the inverter circuit 25 with a time delay of an electrical angle of 30° , using a timer, from the edges of the position signals D_u , D_v , and D_w that are generated every electrical angle of 60° . Thus

20 the excitation coils 14u, 14v, and 14w are supplied with a drive current by the three-phase power supply system, whereby a rotary magnetic field is created in the stator 12, which rotates the rotor 13 and the fan 18. The basis on which to determine the time delay in the switching of the power supply

25 may be the average time of k periods ($k \geq 2$) immediately before the switching. For example, the average time of one turn of the rotor 13, instead of one period of 60° immediately before

the switching.

The layout angle θ can variably be set as shown in equation (2) if consideration is given only to establishing a mutual phase difference of 120° between the detection signals Du, Dv, and Dw. In this embodiment, however, the layout angle θ is set to be 20° so as to minimize discrepancies in the phase difference between the detection signals Du, Dv, and Dw resulting from assembling errors of the brushless motor. The reason for thus setting the layout angle θ is explained below.

In the assembling of the brushless motor, the sensor magnet 19 is attached to the output shaft 17, while the Hole Hall elements 27u, 27v, and 27w are mounted on the circuit board 21, which is then attached to the motor holder 11. Thus, there are cases in which assembling errors accumulated through these assembling steps have some bearing on the relative positions of the sensor magnet 19 and Hole Hall elements 27u, 27v, and 27w. Such errors are within a permissible range of predetermined design tolerances, but cannot entirely be eliminated.

Fig. 3A shows the positional relationship between the sensor magnet 19 and Hole Hall elements 27u, 27v, and 27w when the Hole Hall elements 27u, 27v, and 27w are arranged at an ideal mechanical angle of θ_0 , which is 20° in this embodiment, around the output shaft 17. Fig. 3B shows the positional relationship between the sensor magnet 19 and Hole Hall elements 27u, 27v, and 27w that are displaced relative to each other because of assembling errors.

As can be seen from Figs. 3A and 3B, because of the assembling errors, the angle θ_1 included between the hole Hall elements 27w and 27u around the output shaft 17 and the angle θ_2 included between the hole Hall elements 27u and 27v (hereinafter referred to as "layout angle θ_1 and θ_2 ") are shifted from the angle θ_0 that is ideal from a design point of view (hereinafter referred to as "ideal layout angle θ_0 "). When the sensor magnet 19 after the assembly is offset from an ideal position by Δx and Δy on an X-Y coordinate basis in Fig. 3B, approximate values of the layout angles θ_1 and θ_2 can be obtained from equations (3) to (6), in which r represents the distances from the output shaft 17 to the hole Hall elements 27u, 27v, and 27w when the output shaft 17 is at the ideal location:

$$15 \quad \theta_1 \approx \theta_0 + \Delta\theta_1 \quad \dots \quad (3)$$

$$\theta_2 \approx \theta_0 + \Delta\theta_2 \quad \dots \quad (4)$$

$$\Delta\theta_1 = (d\theta_1/dx) \cdot \Delta x + (d\theta_1/dy) \cdot \Delta y \\ = \{(\cos\theta_0 - 1) \cdot (1/r)\} \cdot \Delta x + \{-\sin\theta_0 \cdot (1/r)\} \cdot \Delta y \quad \dots \quad (5)$$

$$20 \quad \Delta\theta_2 = (d\theta_2/dx) \cdot \Delta x + (d\theta_2/dy) \cdot \Delta y \\ = \{(1 - \cos\theta_0) \cdot (1/r)\} \cdot \Delta x + \{-\sin\theta_0 \cdot (1/r)\} \cdot \Delta y \quad \dots \quad (6)$$

Fig. 4 shows the relationship between the coefficients $|d\theta_1/dx|$, $|d\theta_1/dy|$, $|d\theta_2/dx|$, and $|d\theta_2/dy|$ in equations (3) to (6) and the ideal mechanical layout angles θ_0 obtained by calculations. Coefficients $|d\theta_1/dx|$ and $|d\theta_2/dx|$ are equal, and they increase steadily in proportion to the ideal layout angle θ_0 . Coefficients $|d\theta_1/dy|$ and $|d\theta_2/dy|$ are equal, and they increase in proportion to the ideal layout angle θ_0 in

the range of from 0° to 90° , but then decrease after the angle θ_0 exceeds 90° .

Substituting these coefficients in equations (5) and (6) reveals that respective displacement amounts $\Delta\theta_1$ and $\Delta\theta_2$ of 5 the layout angles θ_1 and θ_2 become smaller with the decrease of the ideal layout angle θ_0 in the range of under 90° , provided that the displacement amounts Δx and Δy are the same. In the range of over 90° of the ideal layout angle θ_0 , on the other hand, the displacement amounts $\Delta\theta_1$ and $\Delta\theta_2$ are heavily 10 dependent on the displacement amounts Δx and Δy , because the coefficients $|d\theta_1/dy|$ and $|d\theta_2/dy|$ decrease while the coefficients $|d\theta_1/dx|$ and $|d\theta_2/dx|$ increase.

In actual applications, the Hole Hall elements 27u, 27v, and 27w need to be disposed away from the power supply 15 terminals 24u, 24v, and 24w so as to avoid adverse effects of any magnetic field created by the supplied current. Thus, the ideal layout angle θ_0 is normally set to be 90° or smaller. In this embodiment, therefore, based on the above calculation results, the Hole Hall elements 27u, 27v, and 27w are disposed 20 with the minimum possible layout angle θ of 20° so as to minimize the displacement amounts $\Delta\theta_1$ and $\Delta\theta_2$ due to the assembling errors.

Fig. 5 and Fig. 6 are waveform charts. Fig. 5 illustrates a state in which the displacement amounts Δx and Δy 25 are zero, whereas the latter illustrates a state in which the sensor magnet 19 has displaced in the X-axis direction and thus $\Delta x > 0$, $\Delta y = 0$. The displacement amount Δx in Fig. 11 which

shows the case with the prior art is the same as that of Fig. 6. Fig. 5 and Fig. 6 illustrate the following:

- (a) Magnetic field of the sensor magnet 19 detected by the hole Hall element 27w;
- 5 (b) Position signal Dw;
- (c) Magnetic field of the sensor magnet 19 detected by the hole Hall element 27u;
- (d) Position signal Du
- 10 (e) Magnetic field of the sensor magnet 19 detected by the hole Hall element 27v;
- (f) Position signal Dv;
- (g) W-phase output state of the inverter circuit 25;
- (h) U-phase output state of the inverter circuit 25;
- 15 (i) V-phase output state of the inverter circuit 25; and
- (j) Input current to the inverter circuit 25 (combined waveform of all the phase currents).

Output states of each phase (g) to (i) vary from one to another of the following:

- H: Switching element on the upper arm side is turned on;
- 20 L: Switching element on the lower arm side is turned on;
- Z: Switching elements on the upper and lower arm sides are both turned off.

If there are no assembling errors, the position signals Du, Dv, and Dw have a mutual phase difference of 120 electrical degrees as shown in Fig. 5, and the current waveforms in each phase are all identical, with the constant time slot of each period 60° of power supply during the constant speed drive. On

the other hand, if there are assembling errors, because the layout angles θ_1 and θ_2 are shifted from 20° , the mutual phase difference between the position signals D_u , D_v , and D_w becomes more than or less than 120° , whereby there are variations in the time slot of the power supply period even during constant speed drive, as shown in Fig. 6, resulting in discrepancies in the current waveforms in each phase. The power supply current thus has a superimposed component that varies in the cycle of 180 electrical degrees.

Nevertheless, a comparison between the brushless motor according to this embodiment in which the layout angles θ_1 and θ_2 are set to be 20° and the prior art brushless motor in which the layout angles θ_1 and θ_2 are set to be 80° clearly shows that the displacement amounts $\Delta\theta_1$ and $\Delta\theta_2$ when the sensor magnet 19 is offset are reduced to less than one third (see Fig. 4). Thereby, the discrepancies in phase difference between the position signals D_u , D_v , and D_w can also be reduced, and generation of a current component that varies in the cycle of an electrical angle of 180° can be suppressed.

As described above, in the brushless motor of this embodiment, the layout angles θ_1 and θ_2 of the Hole Hall elements 27u, 27v, and 27w for detecting the magnetic field of the sensor magnet are set to be 20° , which is the minimum necessary angle for generating position signals D_u , D_v , and D_w with a 120° phase difference. Thereby, even if there is a change in relative positions of the sensor magnet 19 and Hole Hall elements 27u, 27v, and 27w, the displacement amounts $\Delta\theta_1$

and $\Delta\theta_2$ of the layout angles θ_1 and θ_2 are suppressed to a minimum.

Accordingly, as compared to the prior art brushless motor in which no consideration is given to the effects of assembling errors on the displacement amounts $\Delta\theta_1$ and $\Delta\theta_2$ in relation to the arrangement of hole Hall elements 27u, 27v, and 27w, discrepancies in phase difference between the position signals Du, Dv, and Dw are lessened, whereby the varying component superimposed in the phase currents is reduced. Torque variations are thereby diminished, and noise, vibration, and efficiency deterioration caused by resonance with the casing are all suppressed. Because the brushless motor is used as the blower motor of the vehicle air-conditioning system, suppression of noise is particularly advantageous in enhancing the comfort of the vehicle interior for the vehicle occupant.

The brushless motor of the present invention can be constructed by altering the layout of the hole Hall elements 27u, 27v, and 27w on the circuit board 21 and by reversing the output terminals of the hole Hall elements 27v and 27w of the prior art brushless motor, meaning that no additional components are necessary and no cost increase is involved. Since this alteration does not affect the phases of the position signals Du, Dv, and Dw representing the magnetic pole positions of the sensor magnet 19 and rotor magnet, the lead angle control in the prior art motor can also be performed without affecting driving efficiency.

(Second Embodiment)

A second embodiment of the present invention will be described next with reference to Fig. 7, which provides a schematic representation of the electrical structure of the brushless motor. In this embodiment, the sensor magnet 32 and 5 the rotor magnet are 4-pole magnets, unlike the previous embodiment with 6-pole magnets. The layout angle θ of the Hole Hall elements 27u, 27v, and 27w of this 4-pole magnet system should be one of the mechanical angles of 30° , 60° , 120° , or 150° , in accordance with the above equations (1) and (2). 10 To minimize the displacement amounts $\Delta\theta_1$ and $\Delta\theta_2$ of the layout angles θ_1 and θ_2 resulting from assembling errors, 30° is the optimum angle. The same effects as those of the previous embodiment will thereby be achieved.

(Third Embodiment)

15 Fig. 8 illustrates a third embodiment of the present invention, which uses a 2-pole sensor magnet 33 and a rotor magnet. The layout angle θ of the Hole Hall elements 27u, 27v, and 27w of this 2-pole magnet system should be either one of the mechanical angles of 60° or 120° , in accordance with the 20 above equations (1) and (2). To minimize the displacement amounts $\Delta\theta_1$ and $\Delta\theta_2$ of the layout angles θ_1 and θ_2 resulting from assembling errors, 60° is the optimum angle. The same effects as those of the previous embodiment will thereby be achieved.

25 (Other Embodiments)

The present invention should not be limited to the embodiments described above and shown in the accompanying

drawings and various modifications and extensions such as the following are possible.

Although the layout angle θ of the hole Hall elements 27u, 27v, and 27w is set to be 20° in the first embodiment in 5 accordance with the equations (1) to (6) and calculation results shown in Fig. 4, this is not an absolute requirement. If the layout of the circuit board 21 does not permit mounting of the hole Hall elements with such a small angle spacing, then the layout angle θ may be selected from the options given 10 above (40° , 80° , etc.) to be as small as possible. The same applies to the second and third embodiments.

For the magnetic sensors, other hole Hall sensors such as hole Hall ICs may be used in place of the hole Hall elements. Magnetic resistance elements can also be used. The phase 15 adjusting means 28 may include op-amps or inverters to achieve the phase inversion.

Position signals Du, Dv, and Dw having a mutual phase difference of 120 electrical degrees may be generated according to the following. If the mechanical layout angle θ_1 or θ_2 is 20 one of θ_a , $5 \times \theta_a$, $7 \times \theta_a$, $11 \times \theta_a$, and so on ($< 180^\circ$), i.e., if the mechanical layout angle is $(6m + 3 +/ - 2) \times \theta_a$, where m is 0, 1, 2, ..., the position signals Dv, Dw are obtained by inverting the phases of the output signals of the hole Hall elements 27v and 27w. The output signal of the remaining 25 hole Hall element 27u is used as it is as the position signal Du. Alternatively, the output signals of the hole Hall elements 27v and 27w may be used as position signals Dv and Dw,

while the phase of the output signal of the Hall element 27u is inverted to be used as the position signal Du.

The above brushless motor may not only be used as the blower motor of a vehicle air-conditioning system. The power 5 control circuit 23 may be constructed as an external circuit of the brushless motor as part of an overall drive system including the brushless motor. The sensor magnets 19, 32, and 33 can be replaced by using rotor magnets instead, with the magnetic sensors directly detecting the magnetic field of the 10 rotor magnet.

The description of the invention is merely exemplary in nature and, thus, variations that do not depart from the gist of the invention are intended to be within the scope of the invention. Such variations are not to be regarded as a 15 departure from the spirit and scope of the invention.

ABSTRACT OF THE DISCLOSURE

A brushless motor capable of suppressing noise and vibration resulting from relative positional displacement 5 between a sensor magnet and magnetic sensors caused by assembling errors has a 3-phase brushless motor with a 6-pole sensor magnet rotating integrally with a rotor and hole Hall elements arranged with an angular spacing of 20° (mechanical angle). Position signals are obtained from output 10 signals of the hole Hall elements, with the phases of output signals of one or two hole Hall elements being inverted.